decivil universidade de aveiro departamento de engenharia civil

PhD: FIRE DESIGN OF UNIFORM AND TAPERED CLASS 4 STEEL MEMBERS

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Scientific Supervision Team:

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University of Aveiro

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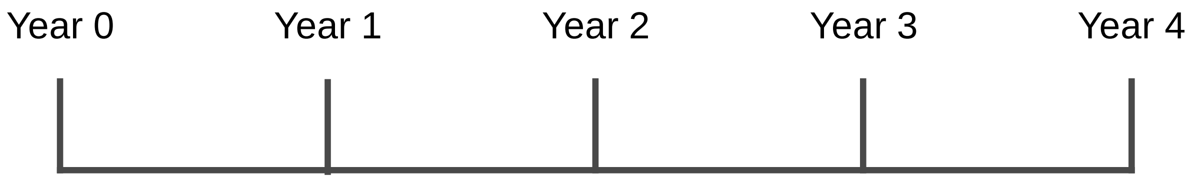
University of Aveiro

Bin Zhao
CTICM

Point of Situation

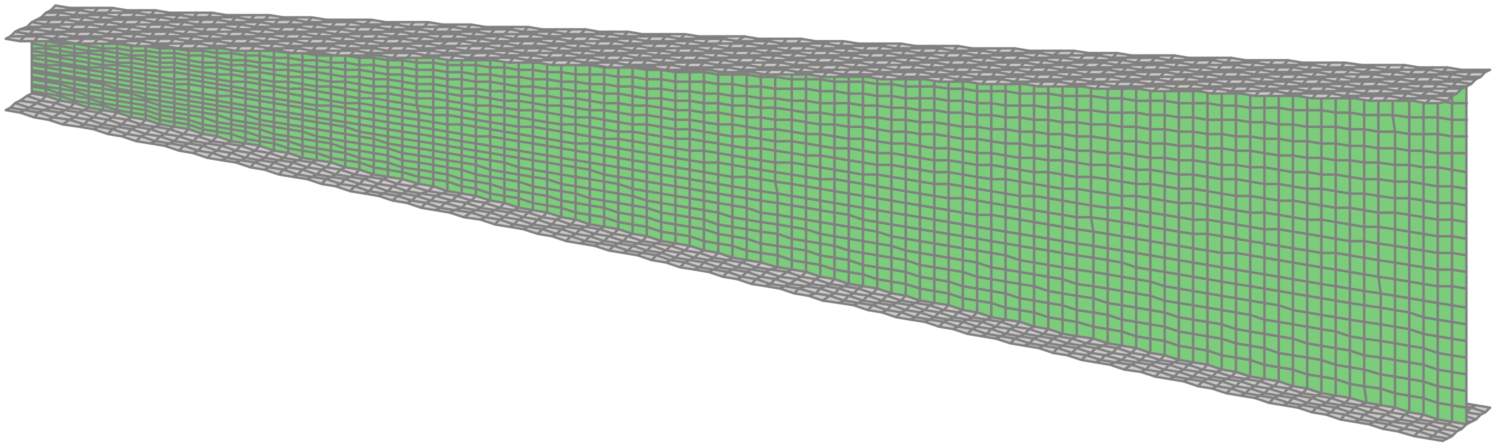
- My PhD started in February 2012



Motivation

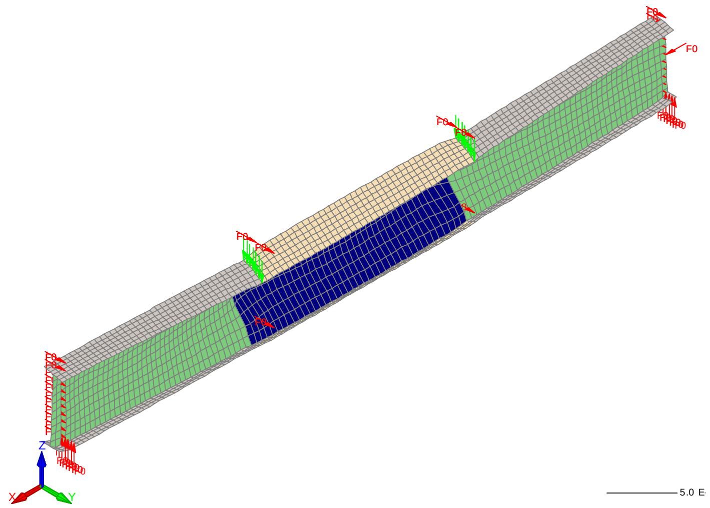
- H or I steel profiles with class 4 cross-section are widely used

- Fire design rules from the Eurocode for these elements have demonstrated to be very conservative



- For tapered members it is not clear if normal temperature design rules can be adapted for fire design

FIDESC4 - FIRE DESIGN OF STEEL MEMBERS WITH WELDED OR HOT-ROLLED CLASS 4 CROSS-SECTION
RFCR-CT-2011-00030, 2011-2014



Partnership:

- CTICM(Coordinator, France)
- LINDAB (Luxembourg, Steel Construction Company)
- Tecnalia (Spain, LABEIN)
- **University of Aveiro (Portugal)**
- Czech Technical University in Prague (Czech)
- University of Liège (Belgium)
- Desmo (Czech, Steel Construction Company)

WP1 Design of fire tests, benchmark study and definition of numerical parametric studies – Coord. CTICM

WP2 Simple bending – Coord. CTICM

WP3 LTB under bending – Coord. CTU

WP4 Axial compression – Coord. ULG

WP5 Combined bending and buckling – Coord. UnivAveiro (UA)

WP6 Development of user-friendly software to apply simple design rules – Coord. UA

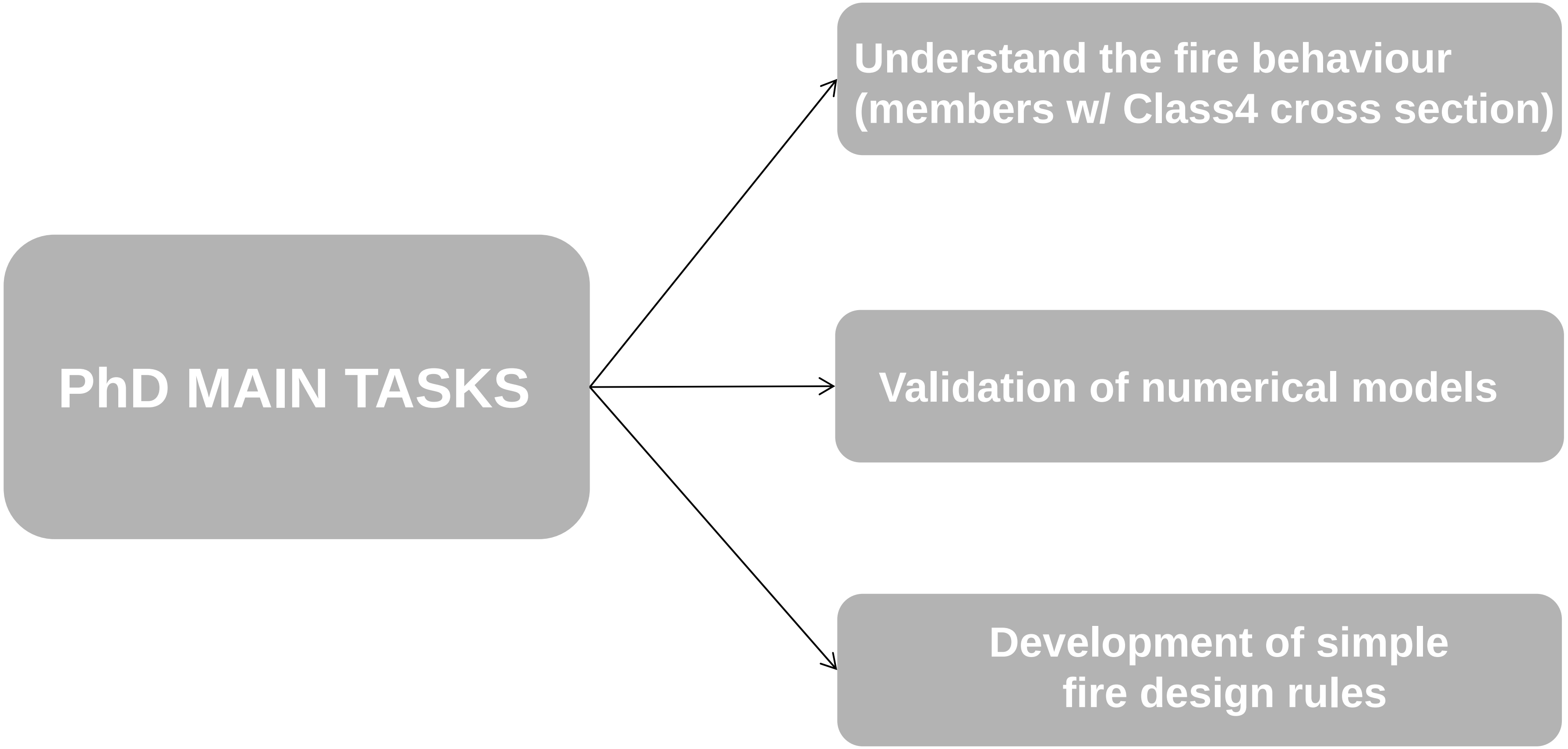
WP7 Global structural analysis – Coord. CTICM

FIRE DESIGN OF UNIFORM AND TAPERED CLASS 4 STEEL MEMBERS objectives:

Study and to **develop simple design rules** for fire design of uniform and tapered steel members with welded or hot-rolled H or I shape class 4 cross-sections

Particulary for **beams** and **beam-columns** as close as possible to the principles of design rules of Eurocode 3 at room temperature

Main Tasks


PhD MAIN TASKS
Understand the fire behaviour (members w/ Class4 cross section)
Validation of numerical models
Development of simple fire design rules

PhD Working Programme

A Bibliographic research.

B Study of lateral-torsional buckling of unrestrained class 4 beams.

C Validation of the used numerical model on the basis of experimental tests (from FIDESC4…).

D Validation of the formulae currently available in Part 1-1 of the Eurocode 3 <u>for the design and stability check of steel tapered members</u> at room temperature and the adaptation to fire situation.

E Parametric study.

F Development of simple fire design rules.

G Final writings of the PhD Thesis.

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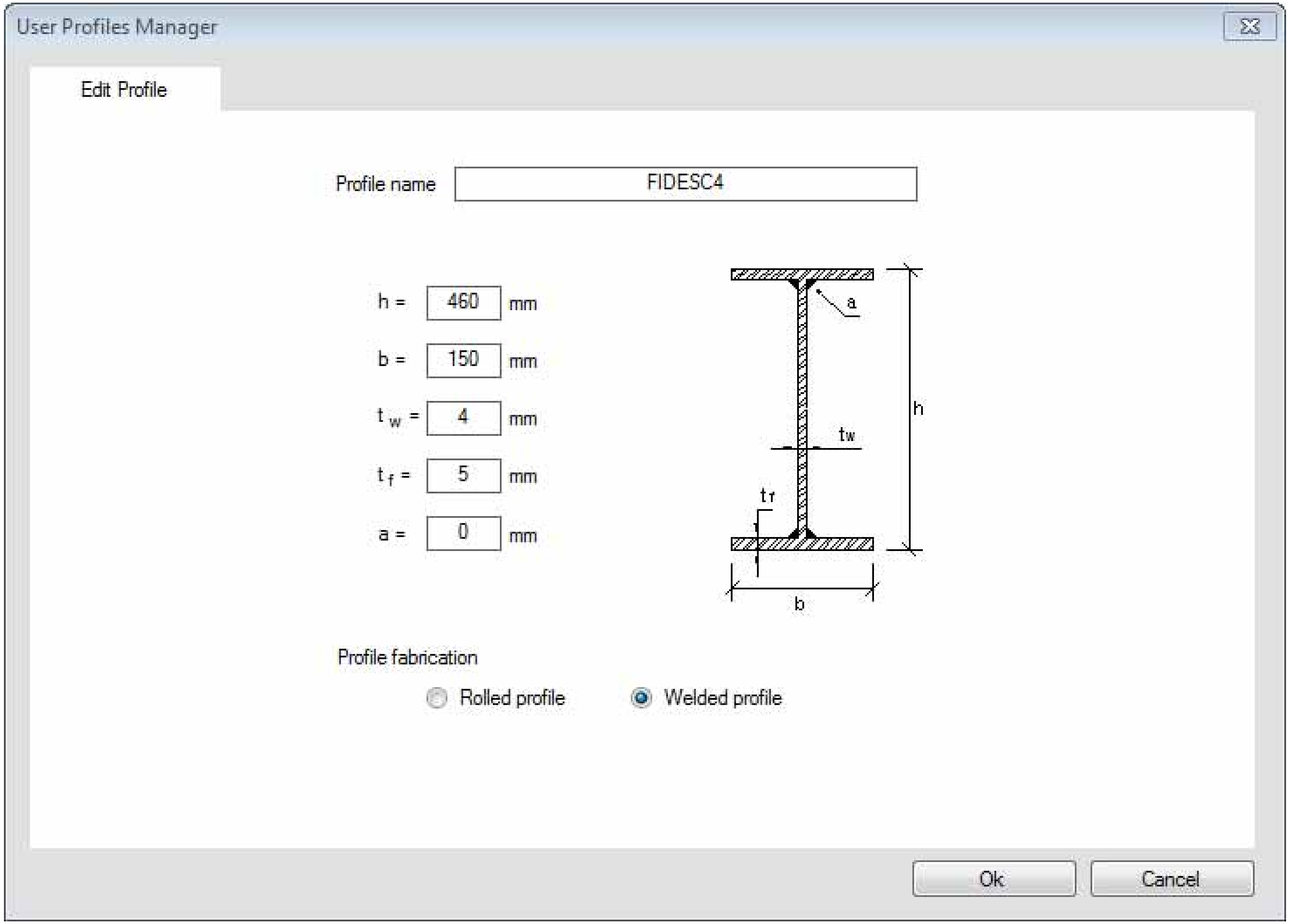
1. Development of software

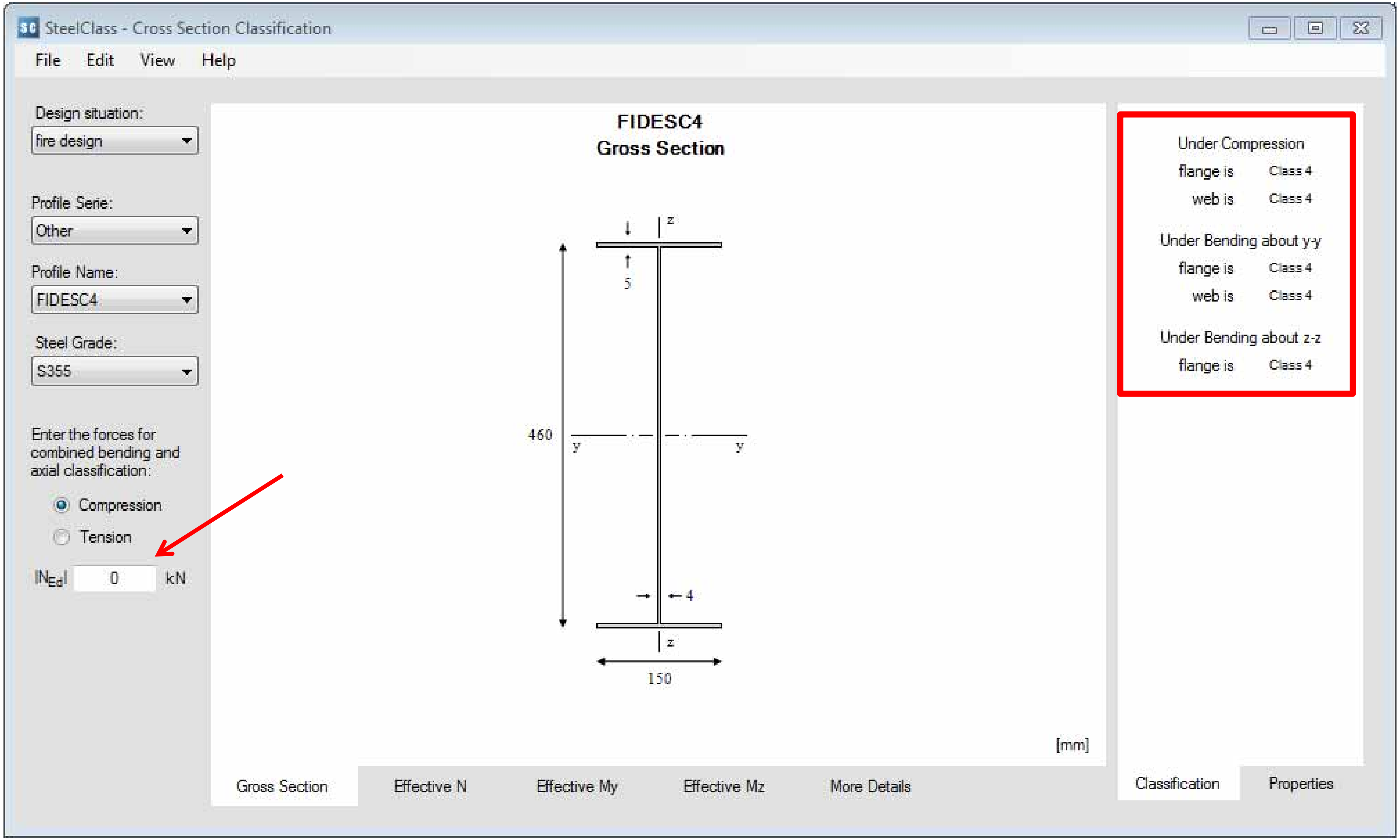
Development of SteelClass, a software for cross section classification…

… and properties!

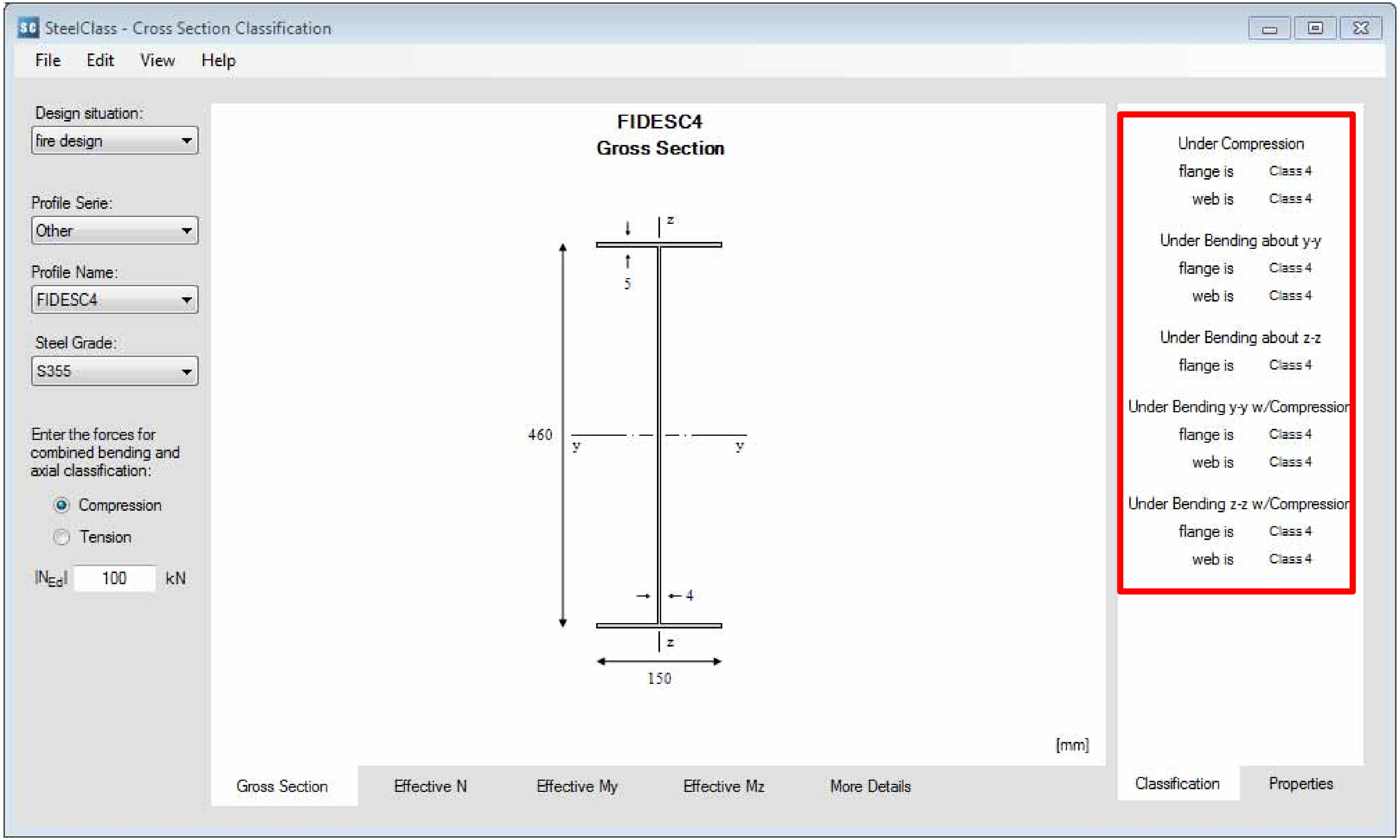
Software developed



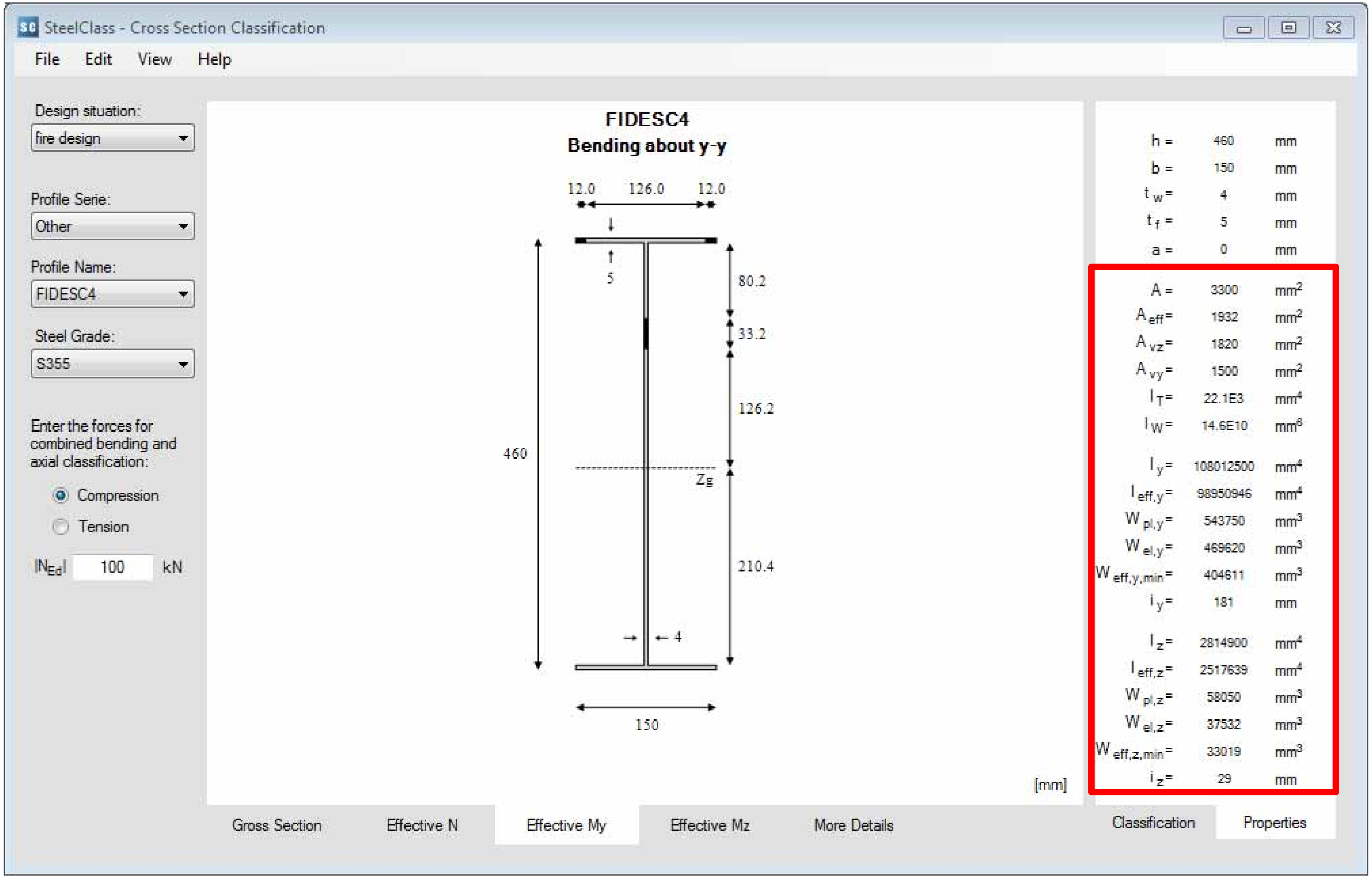
Software developed



Software developed

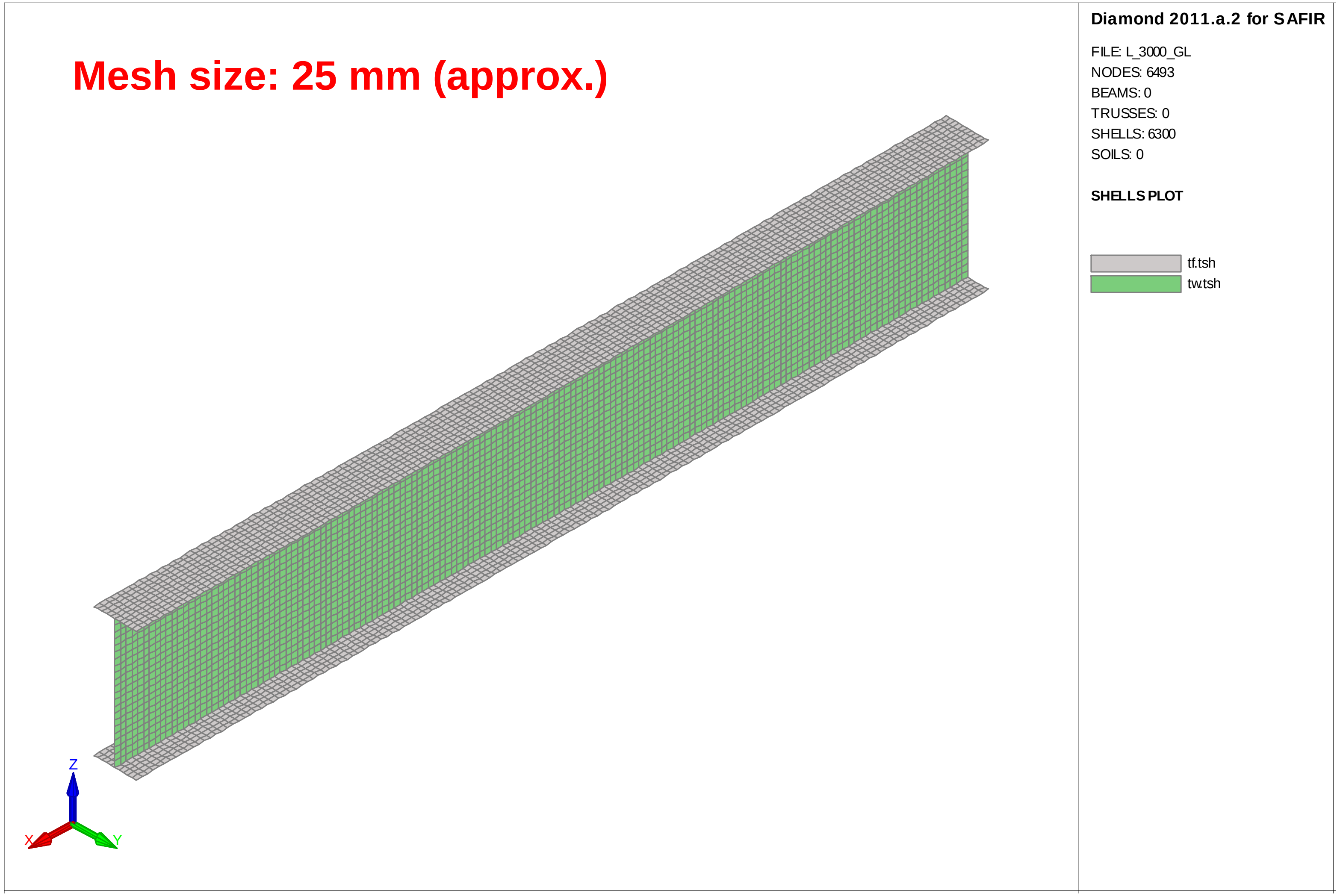


Software developed



2. LTB Study

My LTB shell finite element model



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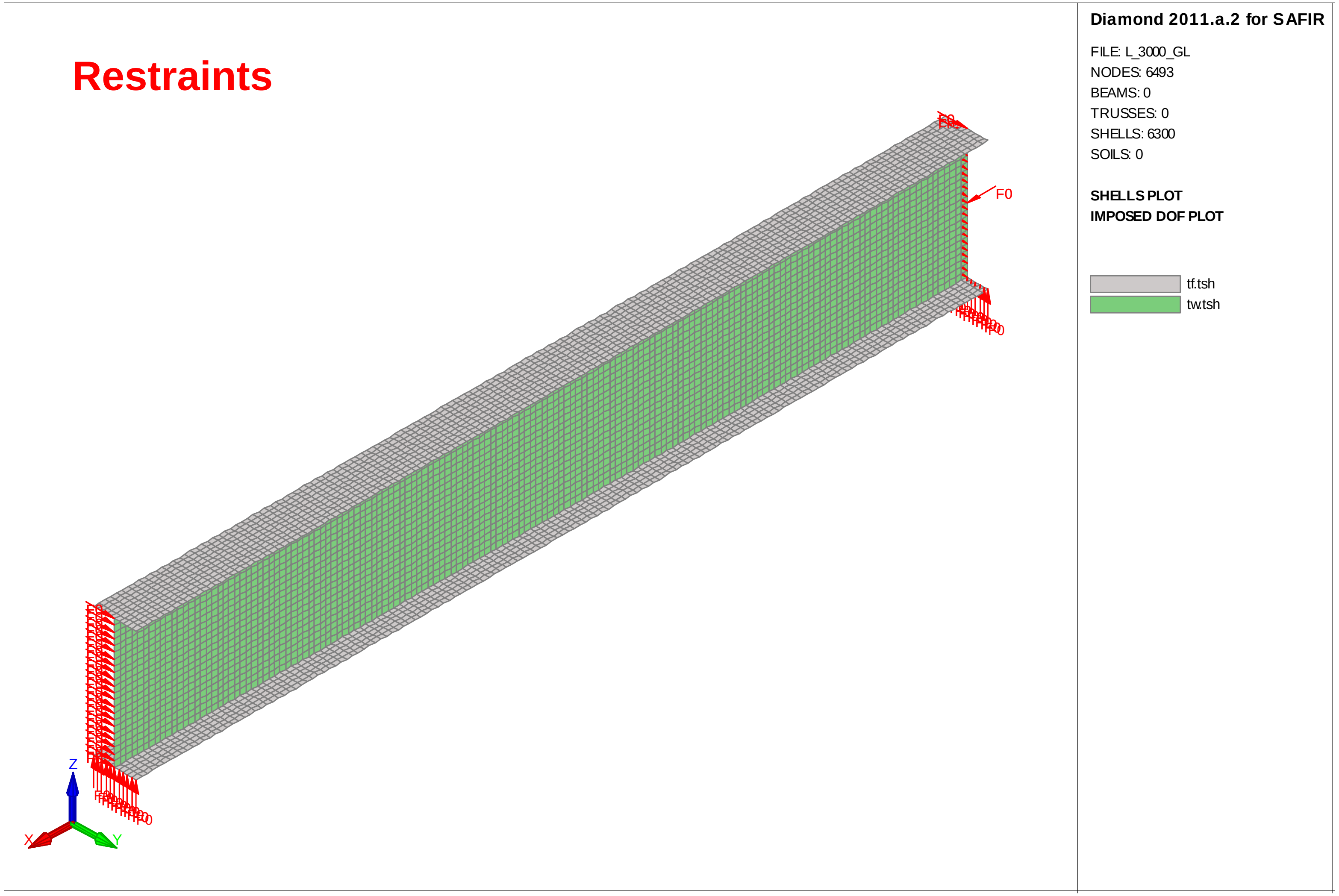

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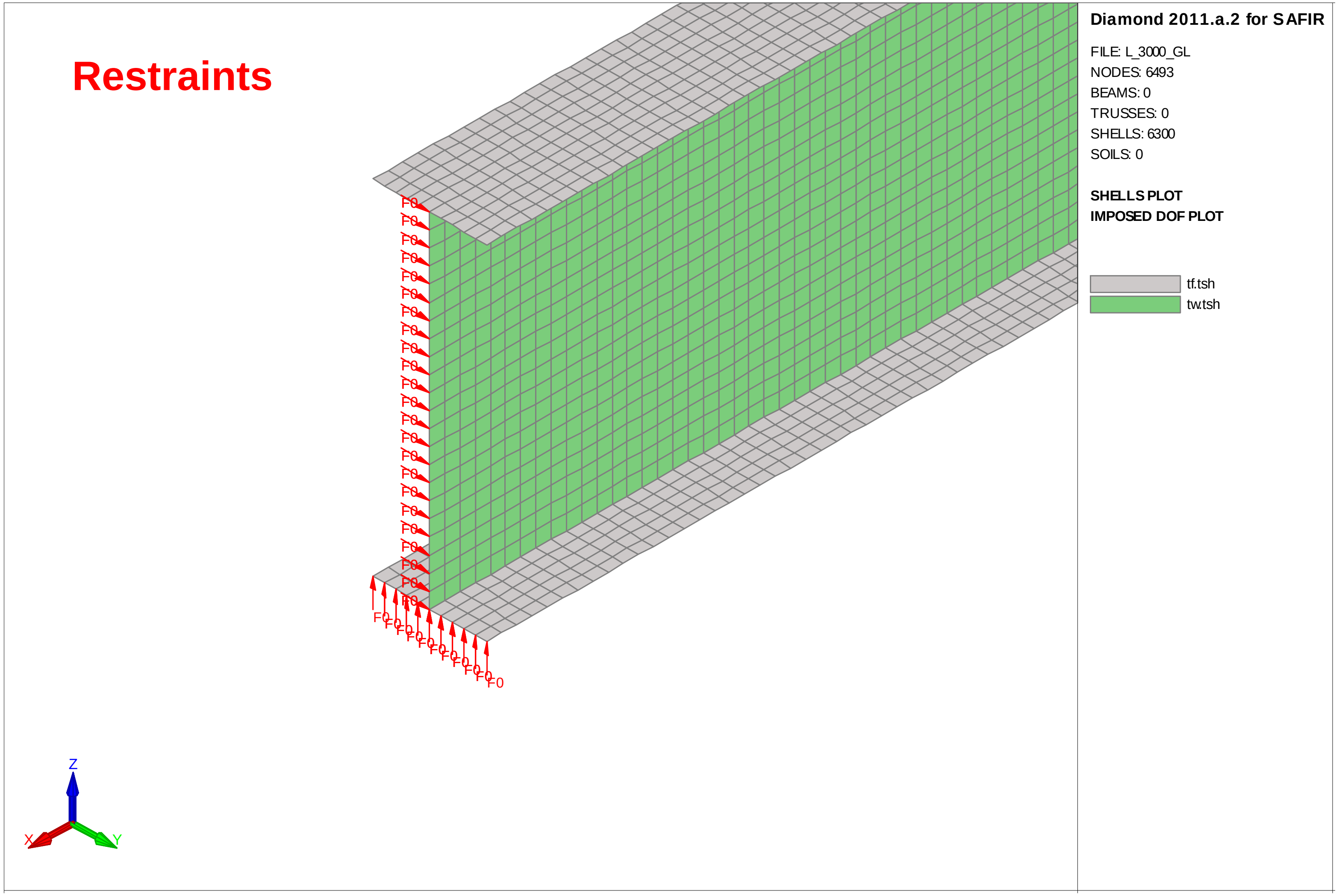
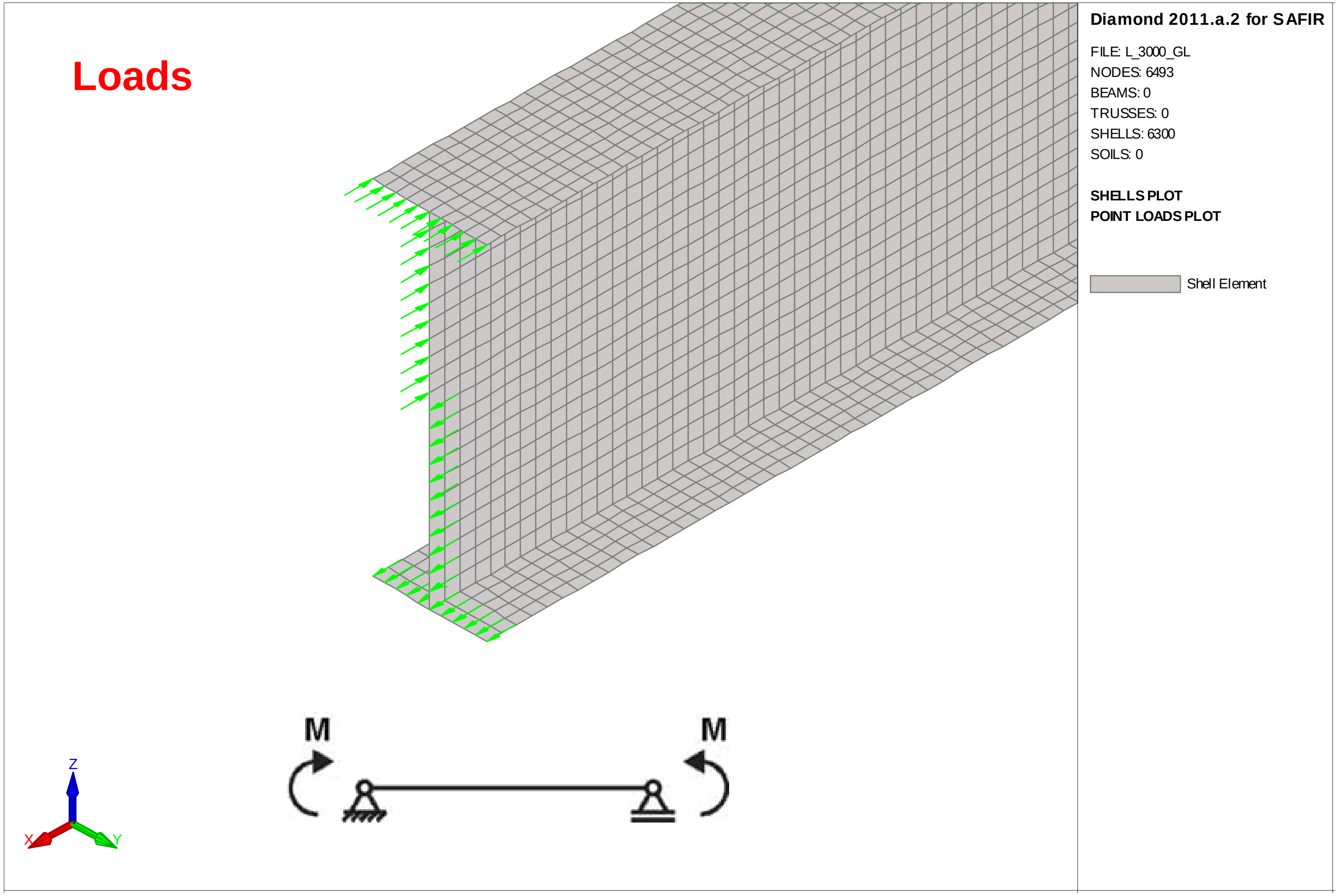


My LTB shell finite element model

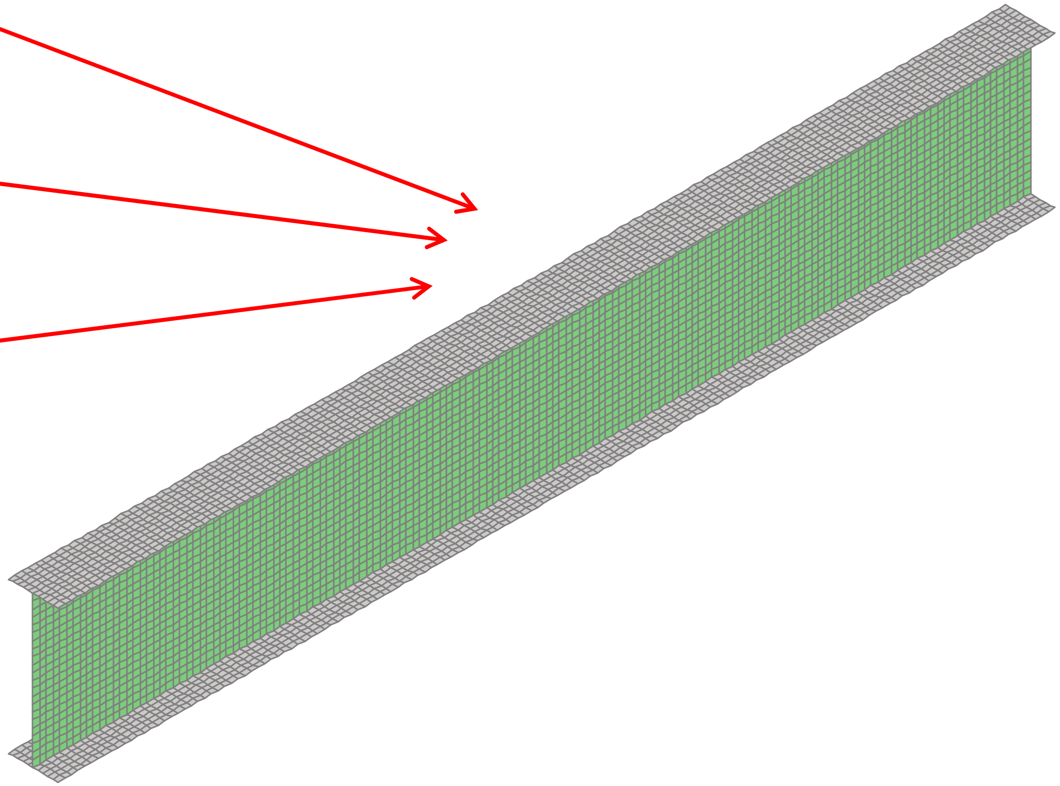


My LTB shell finite element model

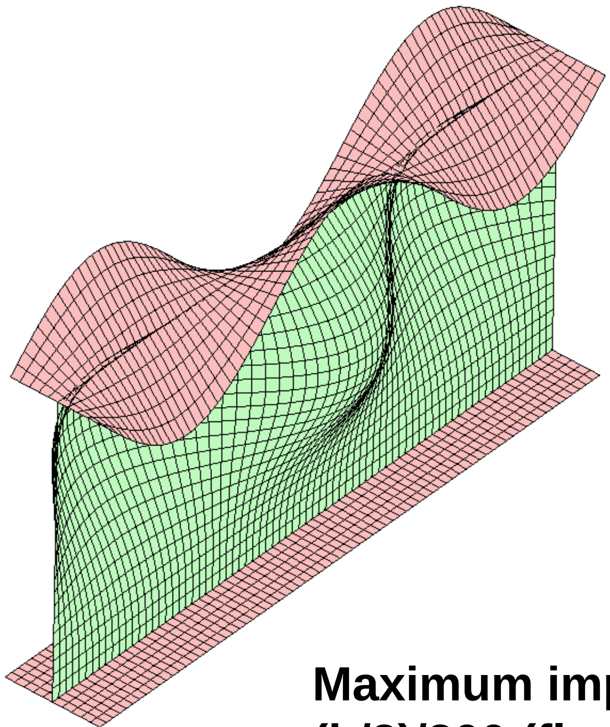
Local imperfections

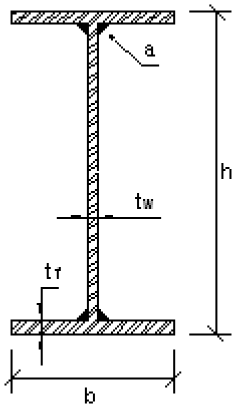
Global imperfections

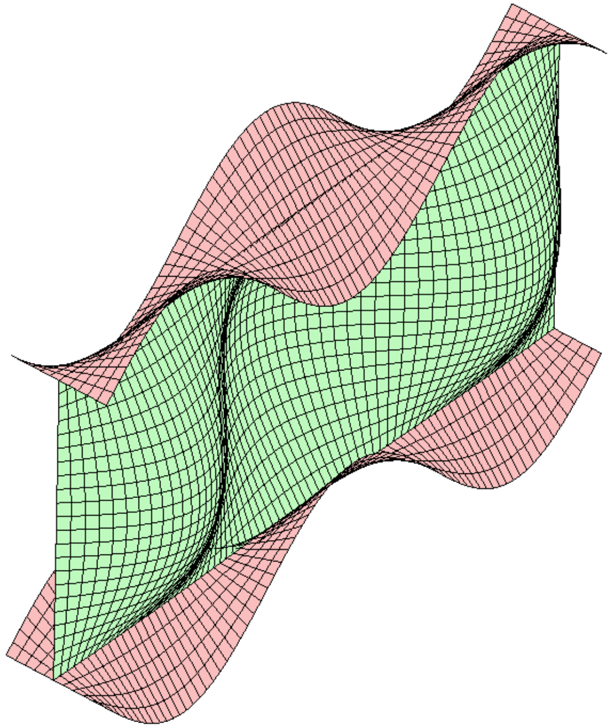
Residual stresses



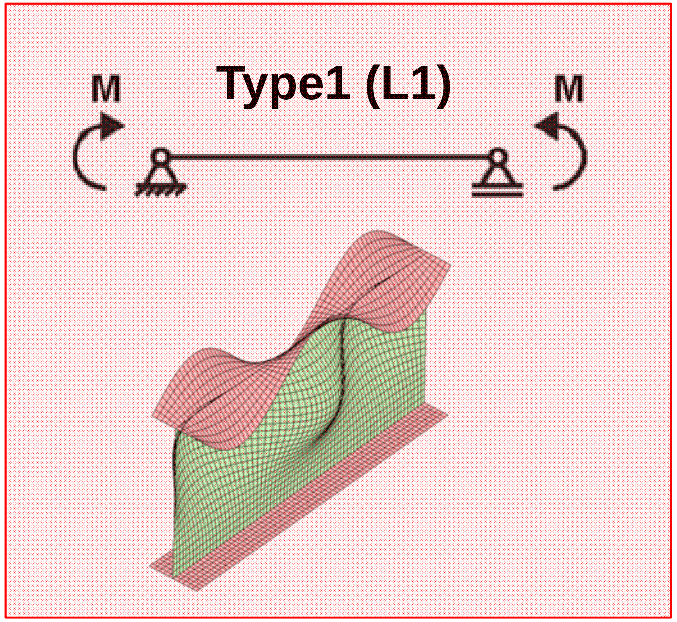
Local Imperfections

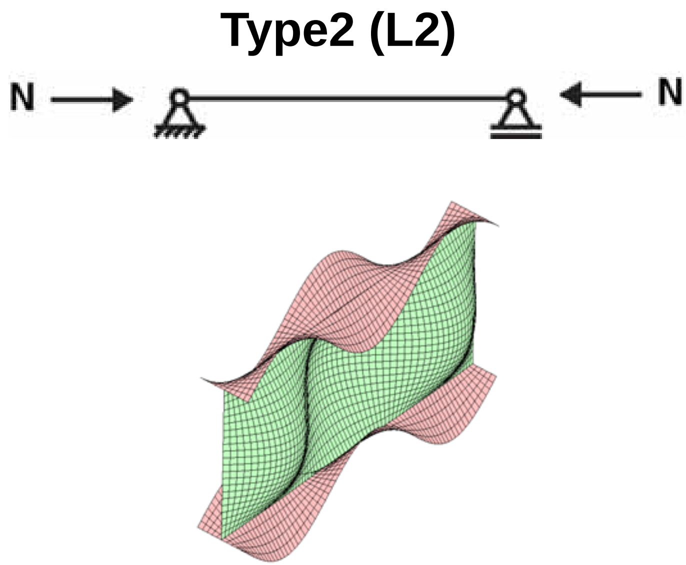






Maximum imperfection amplitude:
(b/2)/200 (flange)
(h-2 tf)/200 (web)



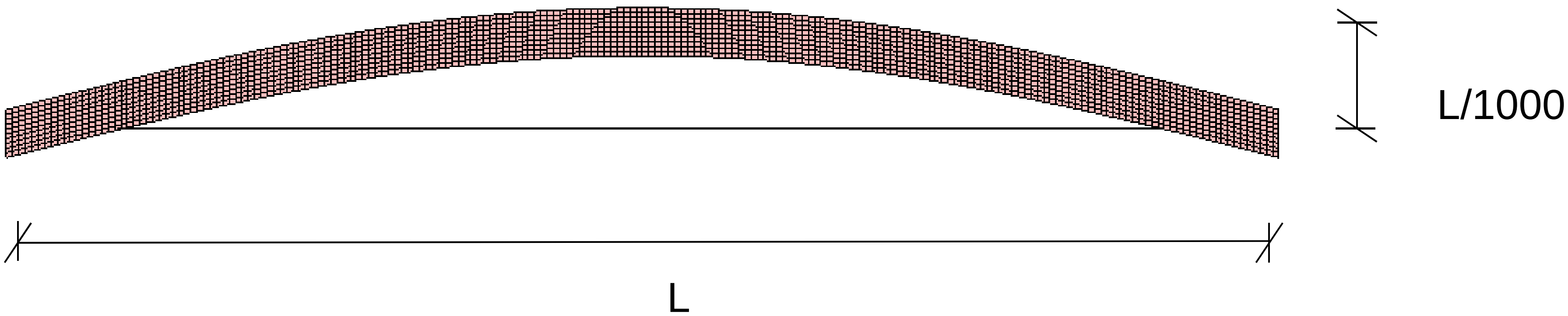


T (ºC)	L1	L2	L1/L2	Dif (%)
20	1094.85750	1098.43750	1.00327	-0.33
400	1221.87000	1225.07000	1.00262	-0.26
500	1104.12000	1104.78750	1.00060	-0.06
600	830.55750	831.74250	1.00143	-0.14

T (ºC)	No Imp	L1	No Imp/L1	Dif (%)
20	1402.475	1094.85750	0.78066	21.93
400	1339.66	1221.87000	0.91207	8.79
500	1204.81	1104.12000	0.91643	8.36
600	919.35	830.55750	0.90342	9.66

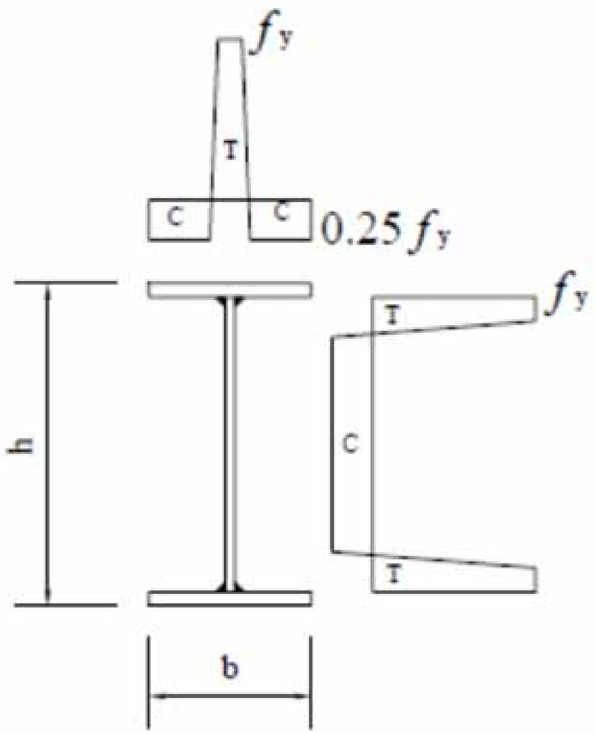
Global Imperfections

A global imperfection of L/1000 was considered.



Residual Stress

Pattern of the residual stress considered in the shell elements (welded profile):

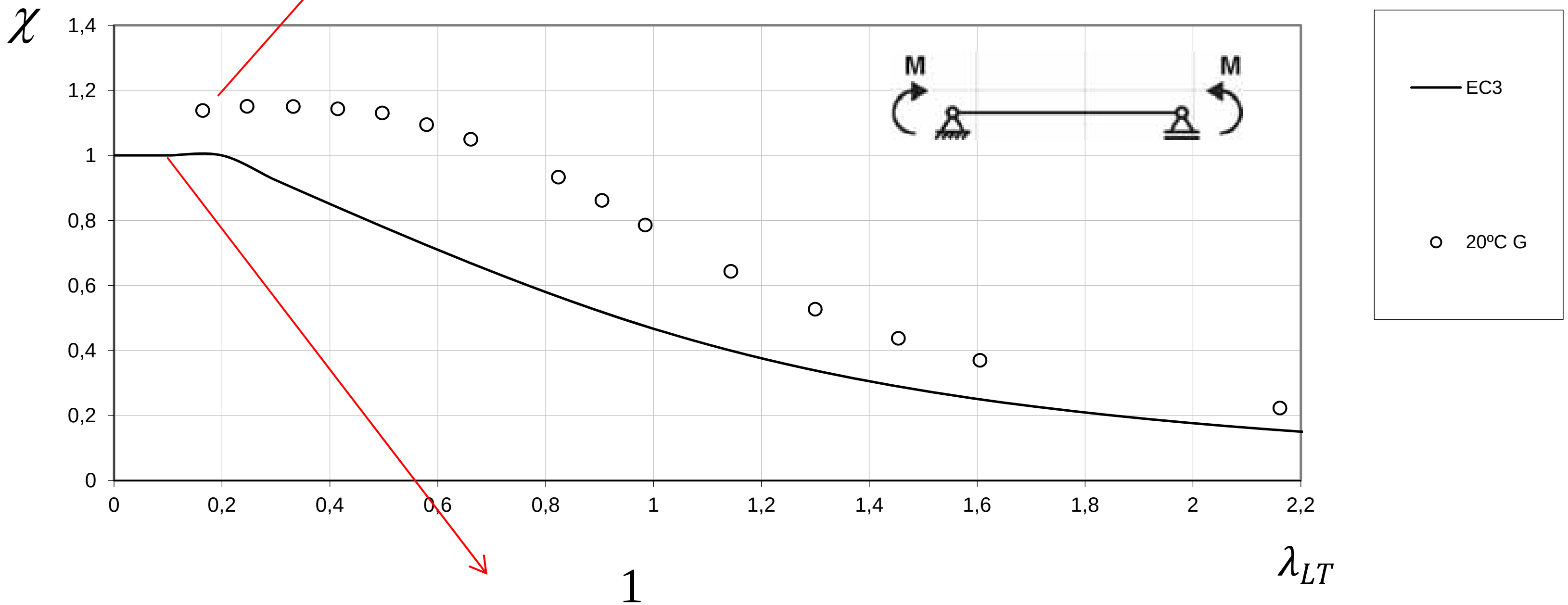


Problem!

If fy=355 MPa SAFIR model doesn’t run. If fy=340 MPa for example, it’s okay!

Room temperature results with only **Global Imperfections**

$$\chi = \frac{M_{SAFIR}}{W_{eff} \times f_y}$$

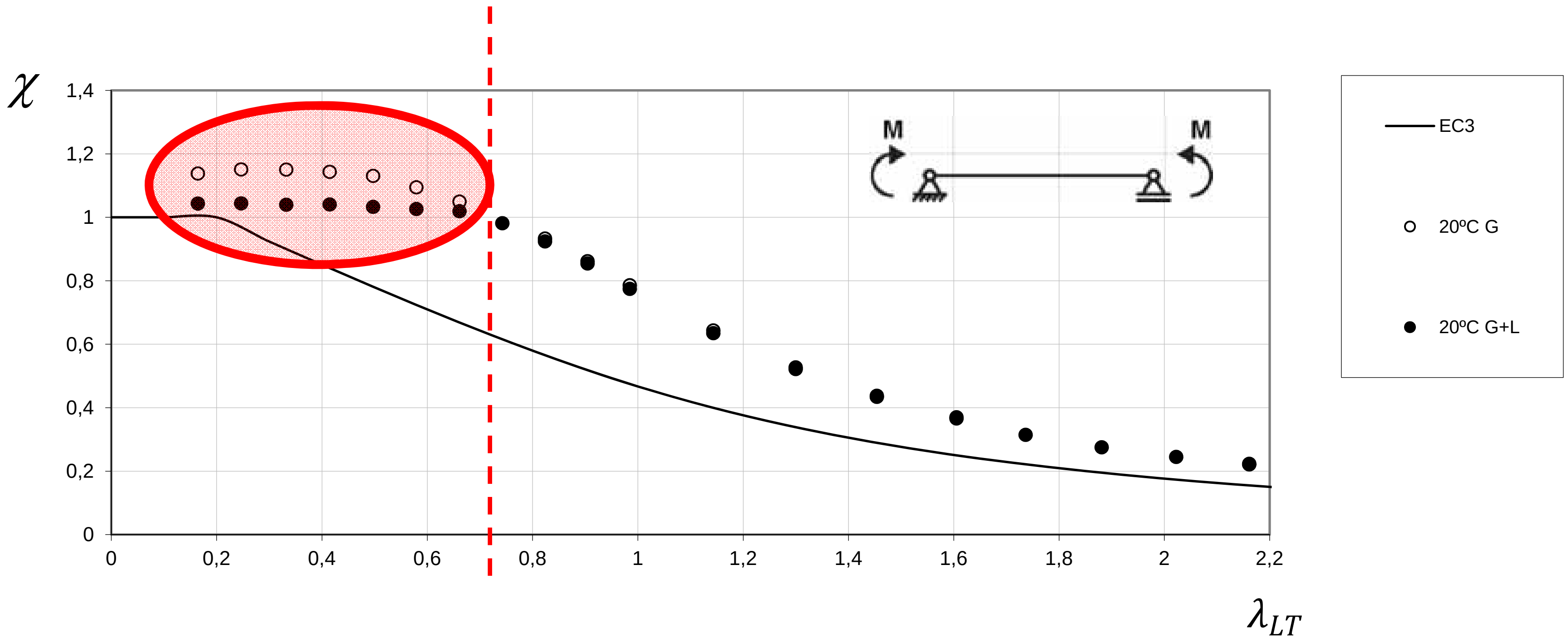


$$\chi_{LT} = \frac{1}{\phi_{LT}^{2} + \sqrt{\phi_{LT}^{2} - \bar{\lambda}_{LT}^{2}}}$$

$$\phi_{LT} = 0.5\left[1 + \alpha_{LT}(\bar{\lambda}_{LT} - 0.2) + \bar{\lambda}_{LT}^{2}\right]$$

Results

Room temperature results with **Global Imperfections + Local Imperfections**

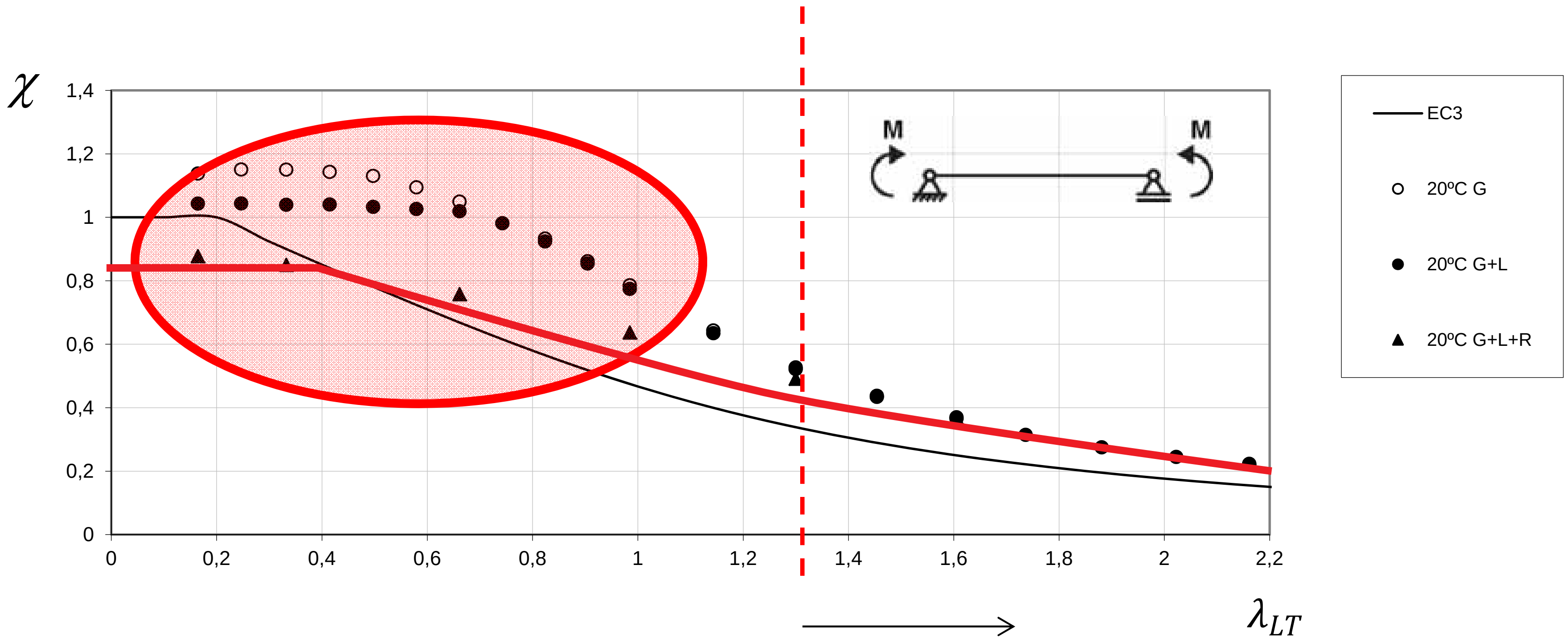


$\lambda_{LT} \sim 0.7$

Results

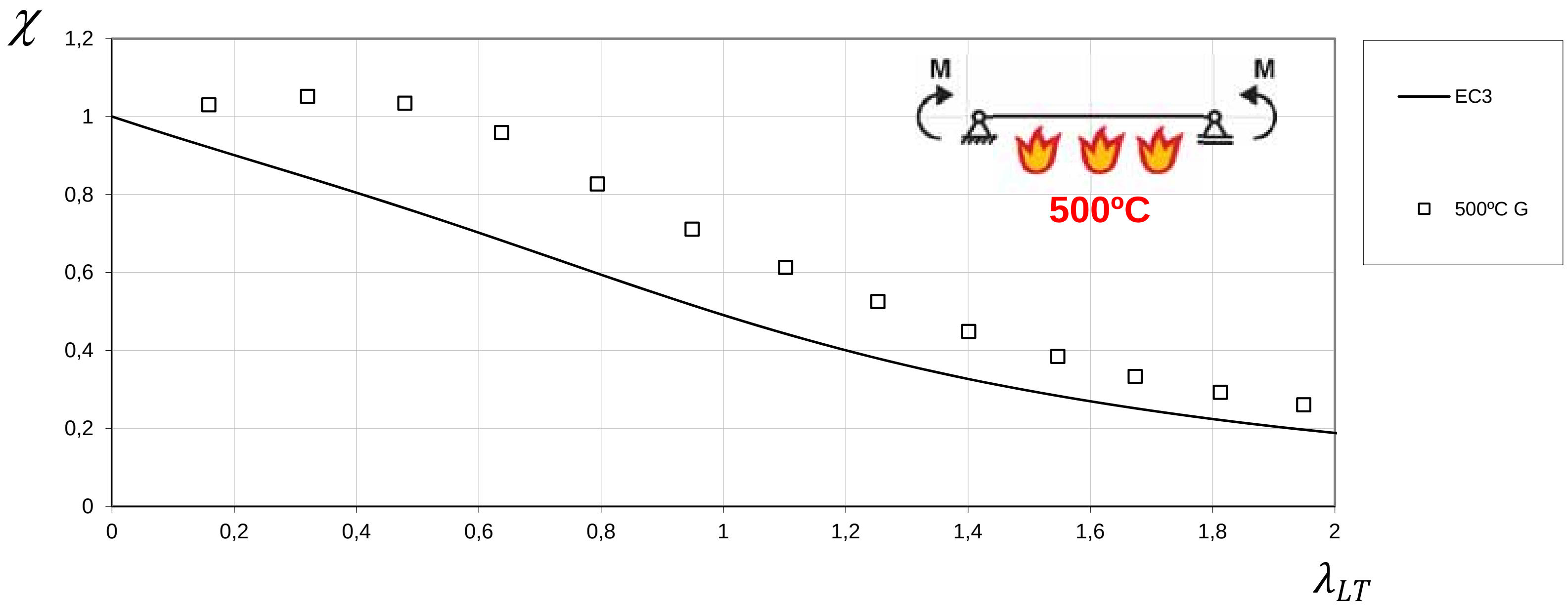
Room temperature results with:

Global Imperfections + Local Imperfections + Residual stresses

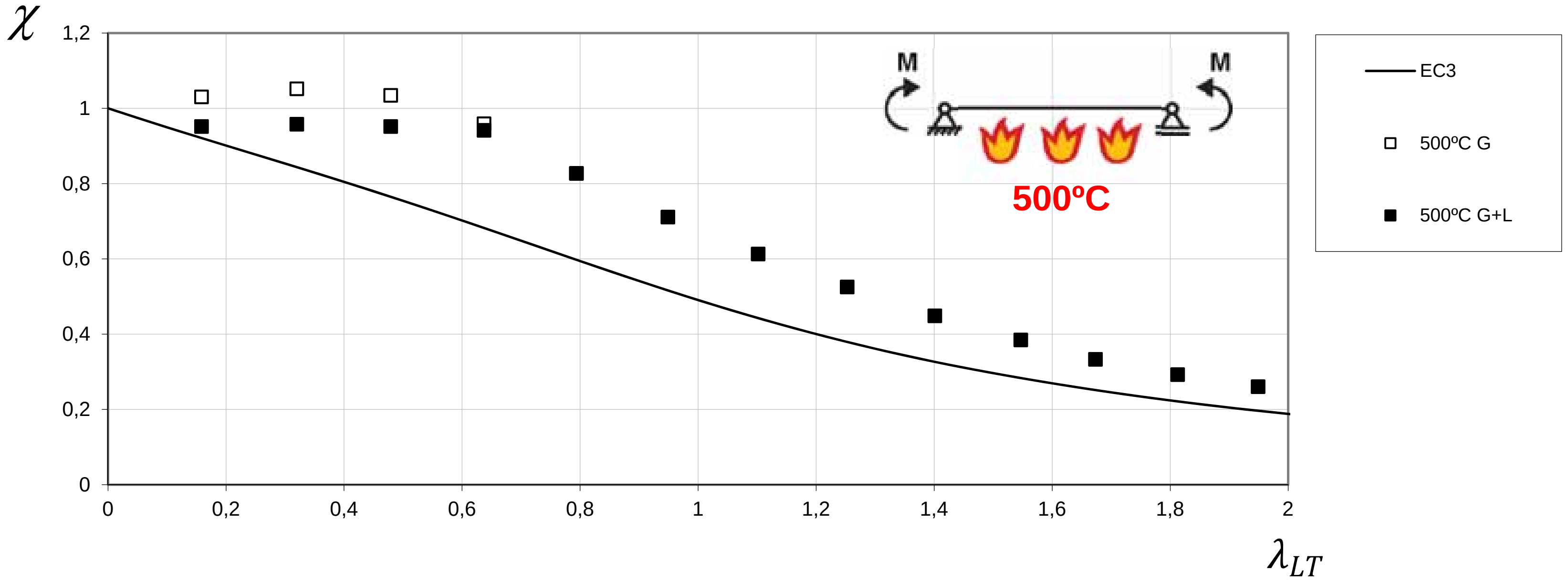


Results

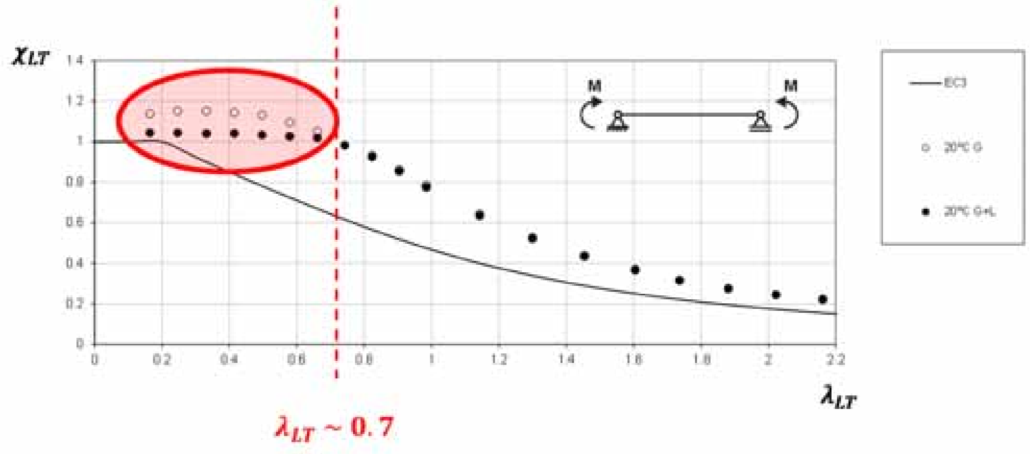
Results at 500ºC with **Global Imperfections**

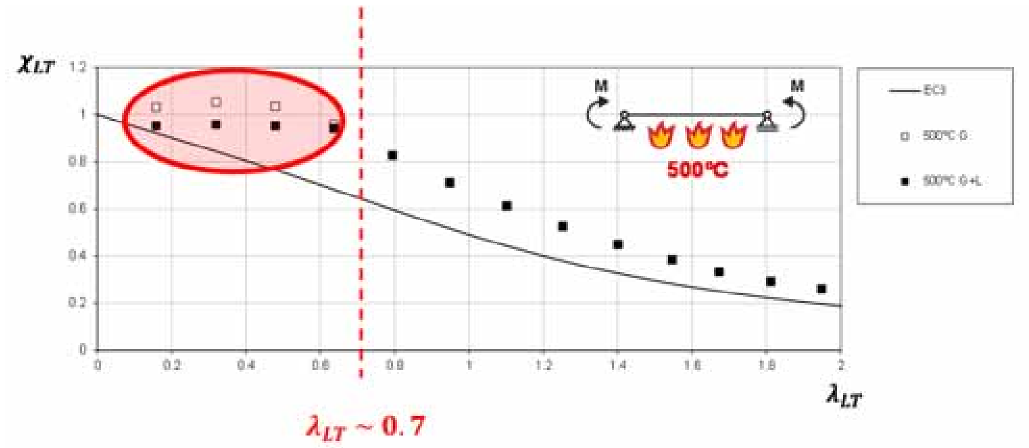


Results at 500ºC with **Global Imperfections + Local Imperfections**



Results





For Class 4:

$$\varepsilon_{\theta} \approx \varepsilon_{20^{\circ}C}$$

$$\bar{\lambda}_{p,\theta} \approx \bar{\lambda}_{20^{\circ}C}$$

$$\bar{\lambda}_p = \sqrt{\frac{f_y}{\sigma_{cr}}} = \sqrt{\frac{f_y}{k_\sigma \frac{\pi^2 E t^2}{12(1-\nu^2)b^2}}} = \frac{b/t}{\sqrt{k_\sigma}\sqrt{\frac{\pi^2}{12(1-\nu^2)}}} \frac{1}{\sqrt{\frac{E}{f_y}}} =$$

$$= \frac{b/t}{\sqrt{k_\sigma}\sqrt{\frac{\pi^2}{12(1-\nu^2)}}\sqrt{\frac{210000}{235}}} \frac{1}{\sqrt{\frac{235}{f_y}}\sqrt{\frac{E}{210000}}} =$$

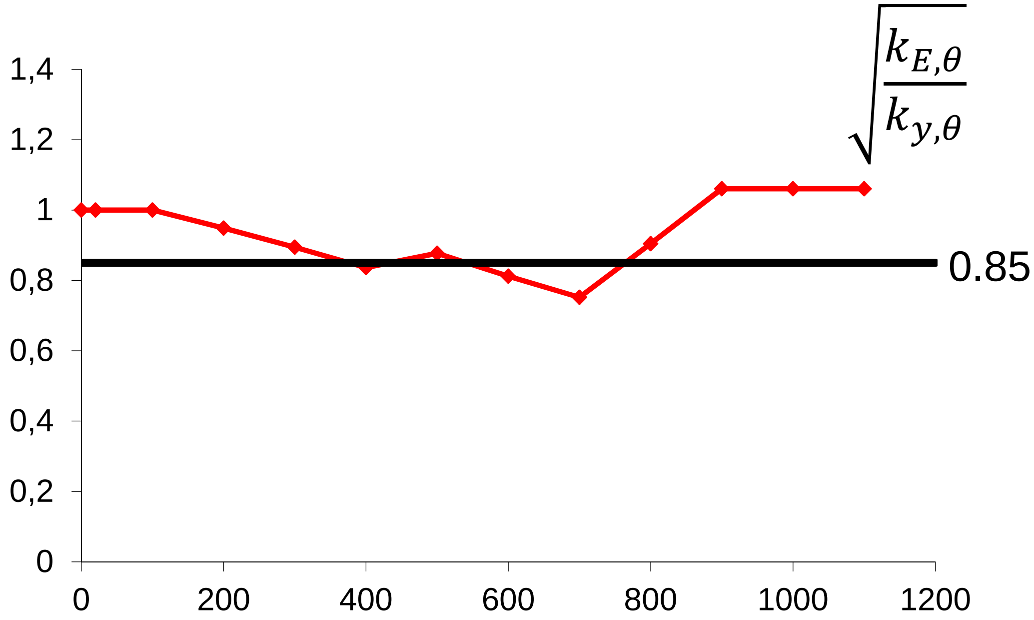
$$= \frac{b/t}{28.4\sqrt{k_\sigma}} \frac{1}{\sqrt{\frac{235}{f_y}}\sqrt{\frac{E}{210000}}} = \frac{b/t}{28.4\sqrt{k_\sigma}} \frac{1}{\varepsilon} = \frac{b/t}{28.4\varepsilon\sqrt{k_\sigma}}$$

$$\varepsilon = \sqrt{\frac{235}{f_y}}\sqrt{\frac{E}{210000}} \quad \text{with } f_y \text{ and } E \text{ in MPa}$$

Room Temperature: $$\varepsilon_{20°C} = \sqrt{\frac{235}{f_y}}$$

High Temperature:

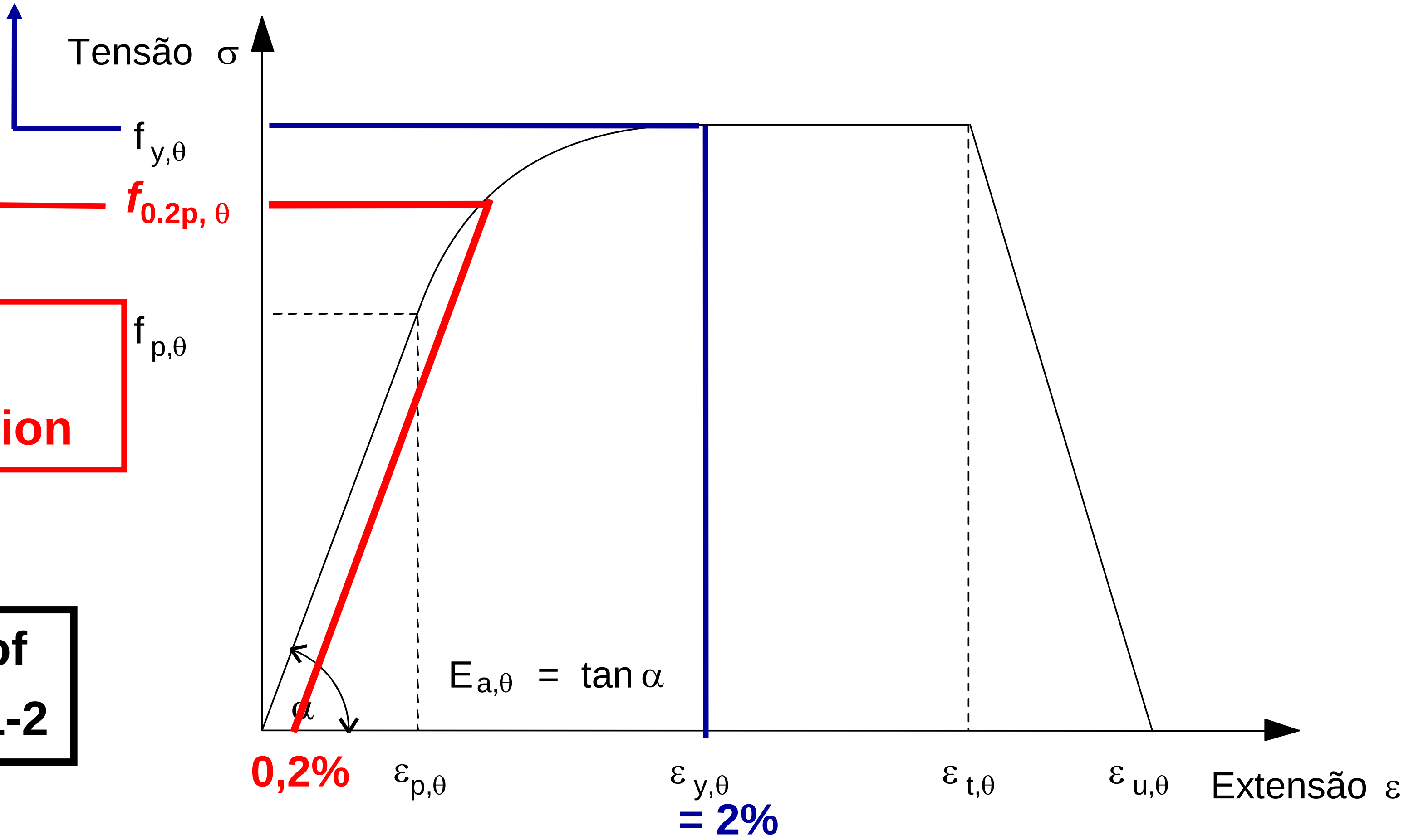
$$\varepsilon_{\theta} = \sqrt{\frac{235}{f_{y,\theta}}}\sqrt{\frac{E_{\theta}}{210000}} = $$
$$= \sqrt{\frac{235}{k_{y,\theta} f_y}}\sqrt{\frac{k_{E,\theta} E}{210000}} = $$
$$= \sqrt{\frac{k_{E,\theta}}{k_{y,\theta}}}\sqrt{\frac{235}{f_y}}\sqrt{\frac{E}{210000}} = $$
$$= \sqrt{\frac{k_{E,\theta}}{k_{y,\theta}}}\sqrt{\frac{235}{f_y}} \approx 0.85\sqrt{\frac{235}{f_y}}$$



Class 1, 2 and 3 cross-section

Class 4 Cross-section

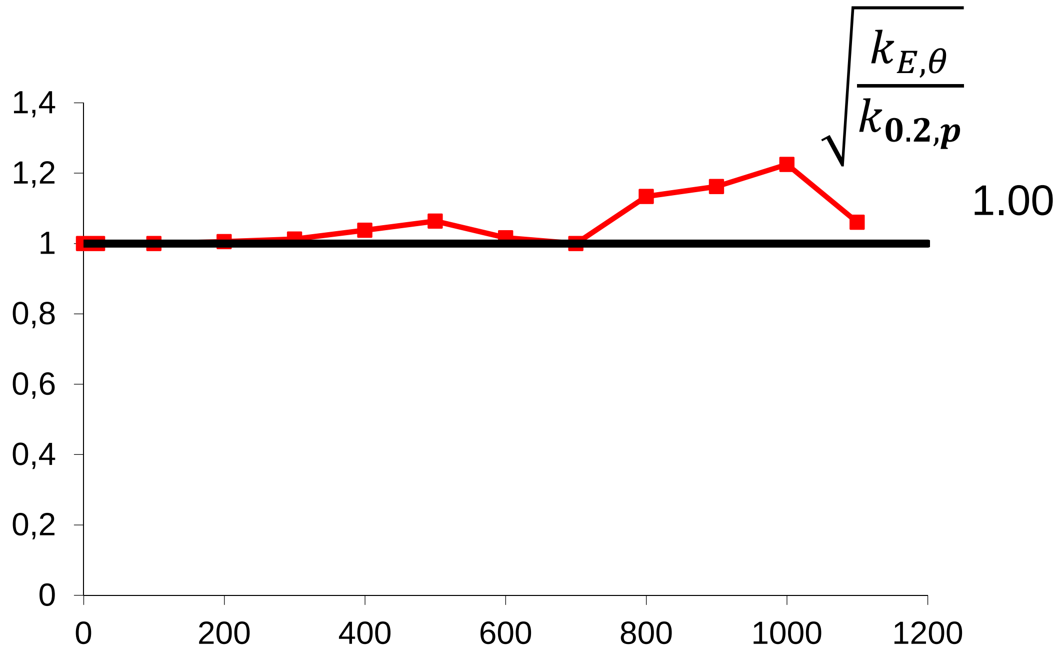
Annex E of EN 1993-1-2



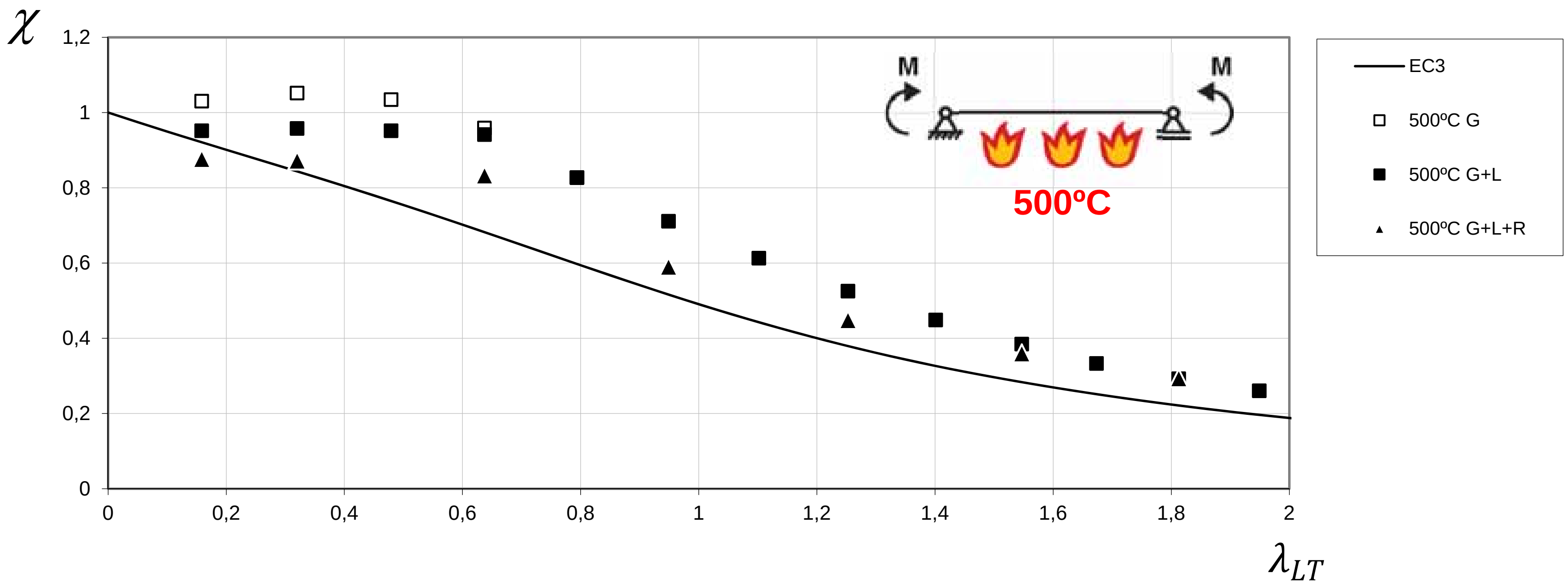
Results

High Temperature (Class 4):

$$\varepsilon_\theta = \sqrt{\frac{k_{E,\theta}}{k_{0.2,p}}}\sqrt{\frac{235}{f_y}} \approx 1.00\sqrt{\frac{235}{f_y}}$$

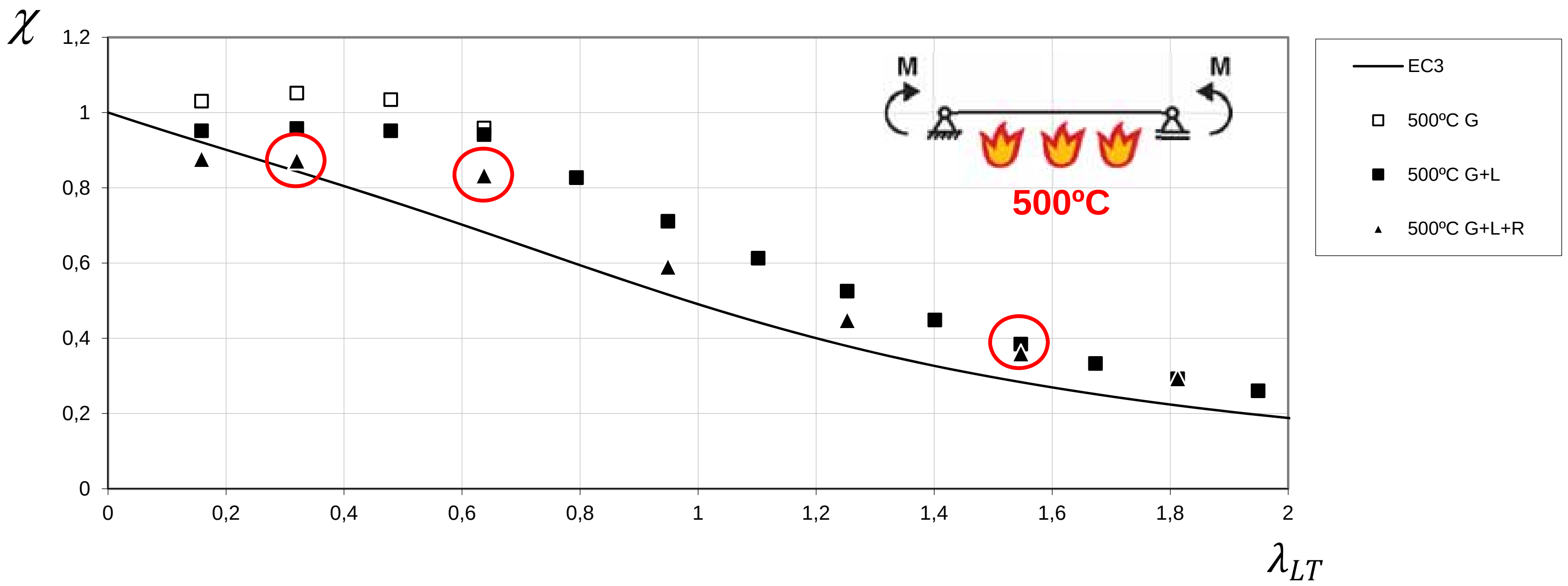


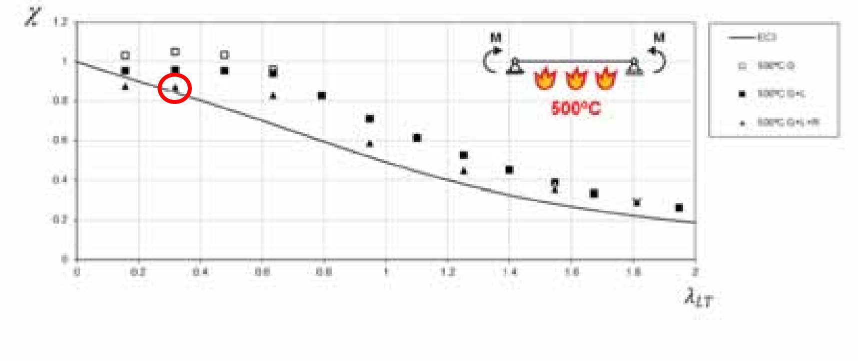
Results at 500ºC with **Global Imperf. + Local imperf. + Residual Stresses**

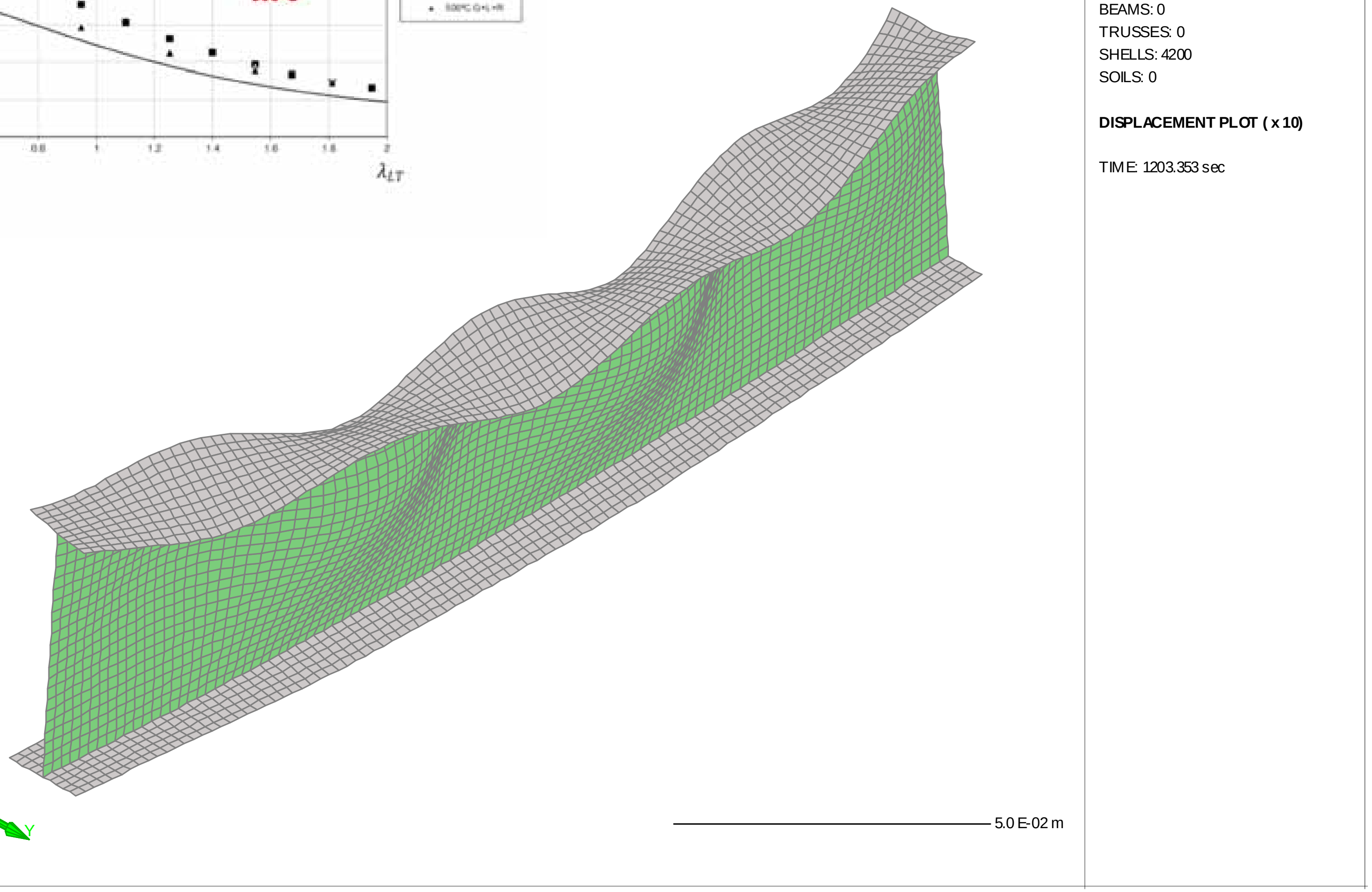


Results

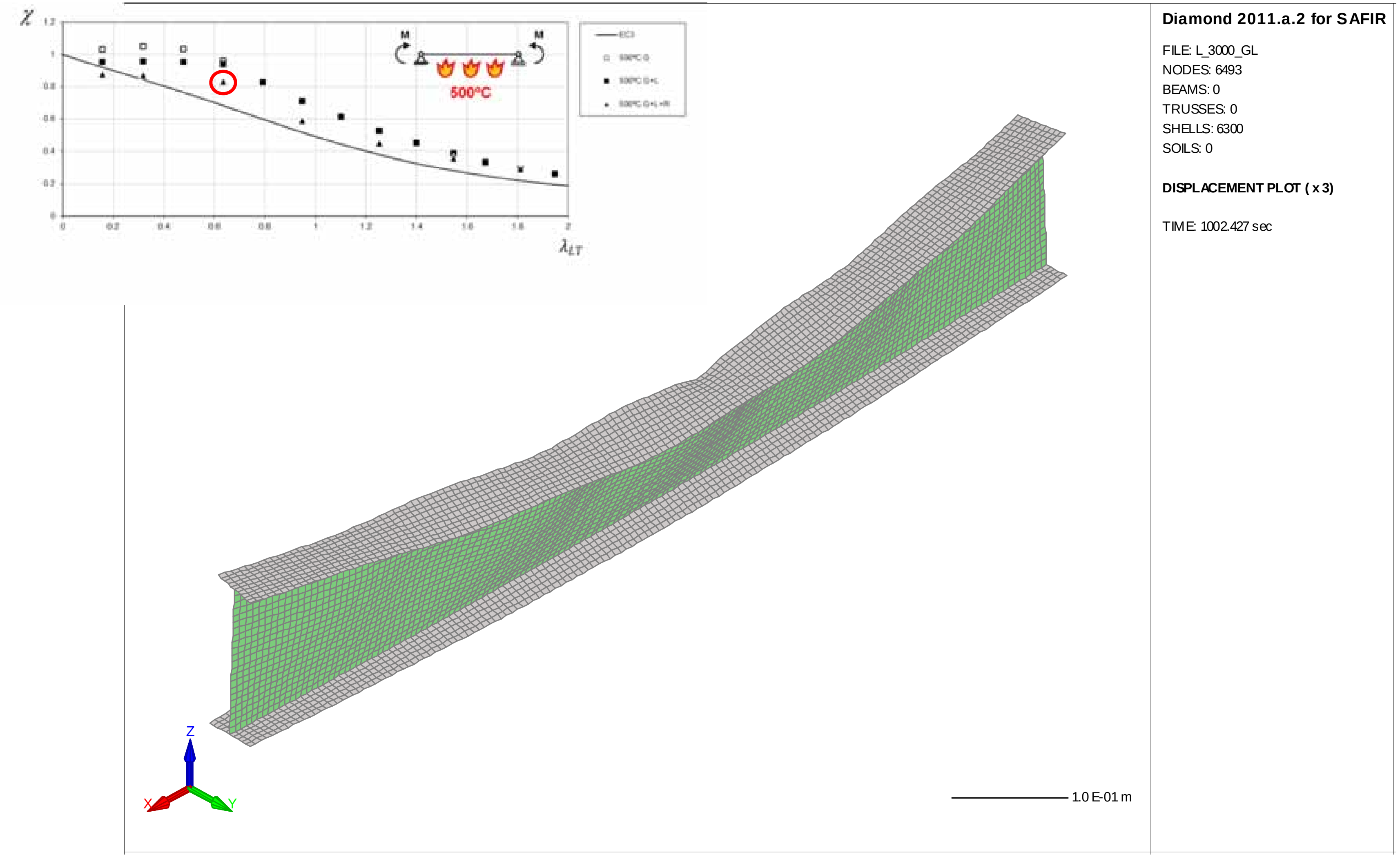
Results at 500ºC with **Global Imperf. + Local imperf. + Residual Stresses**




χ
1.2
1
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
λ_{LT}
M
M
500°C

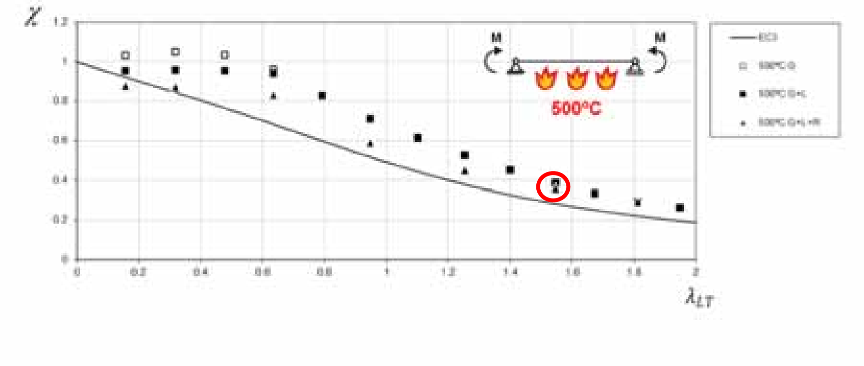

Diamond 2011.a.2 for SAFIR
FILE: L_2000_GL
NODES: 4343
BEAMS: 0
TRUSSES: 0
SHELLS: 4200
SOILS: 0
DISPLACEMENT PLOT (x 10)
TIME: 1203.353 sec
5.0 E-02 m
Z
X
Y

Results

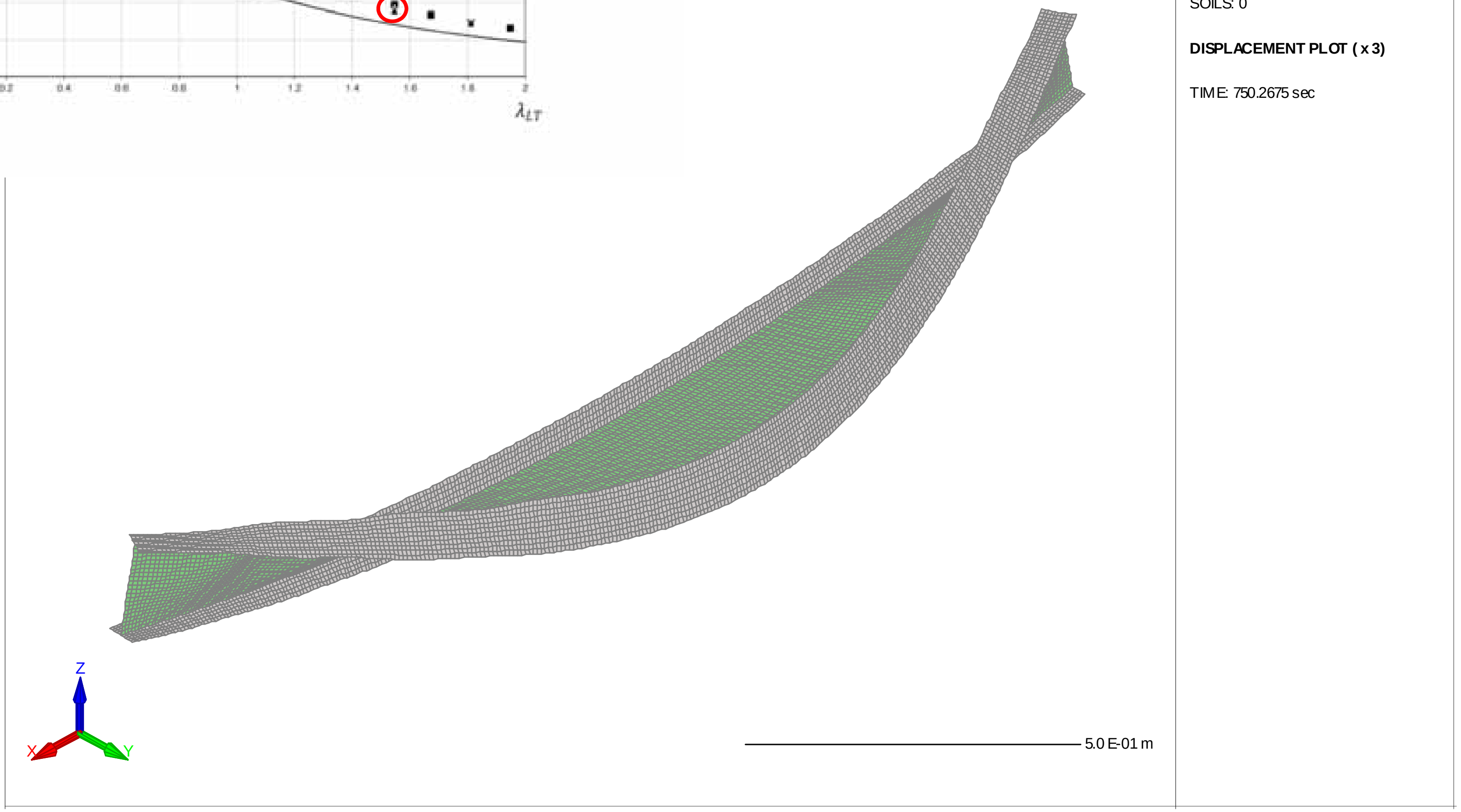


500°C
M
M
Diamond 2011.a.2 for SAFIR
FILE: L_3000_GL
NODES: 6493
BEAMS: 0
TRUSSES: 0
SHELLS: 6300
SOILS: 0
DISPLACEMENT PLOT (x 3)
TIME: 1002.427 sec
1.0 E-01 m

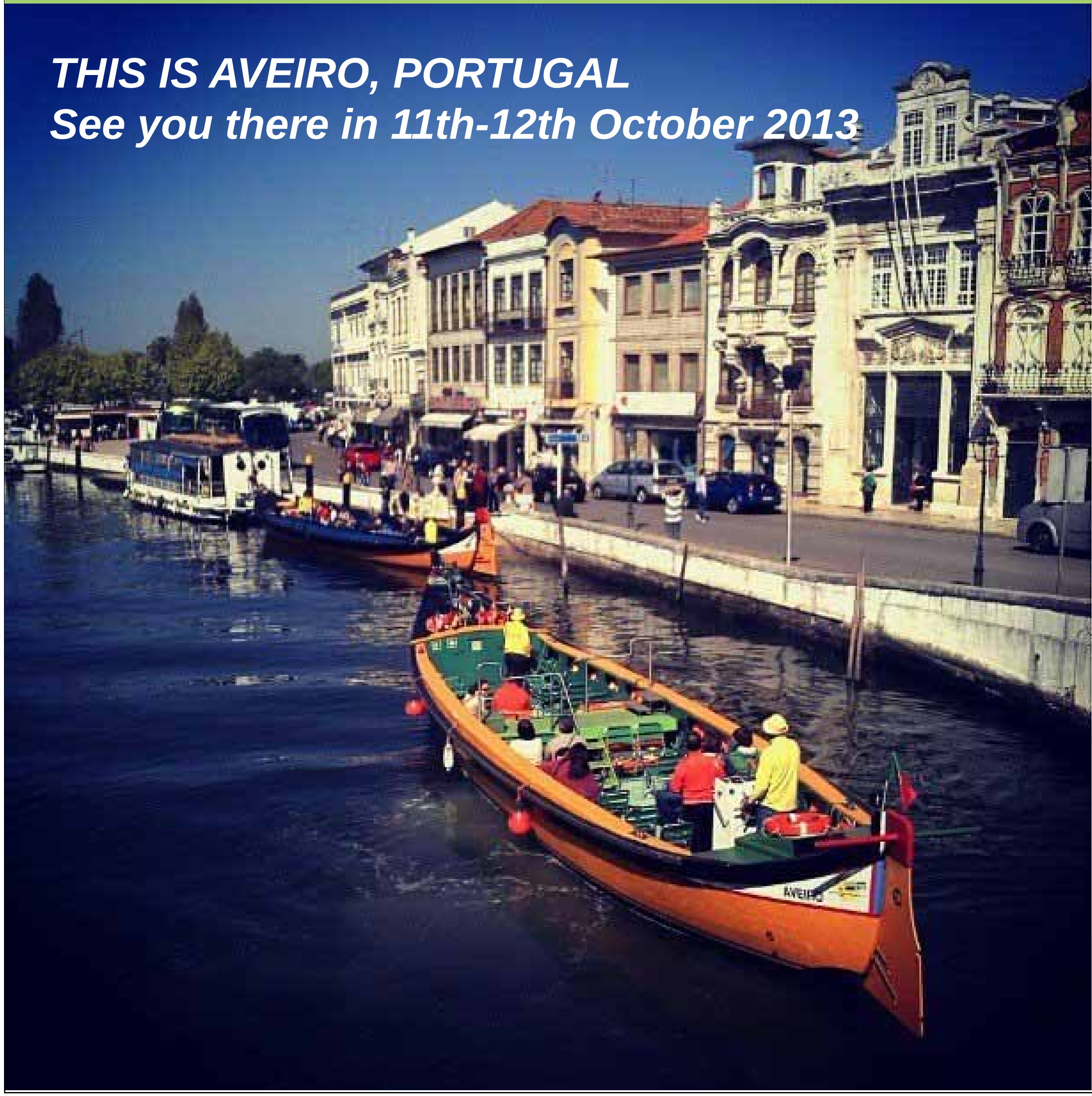
Results



χ
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
λLT
M
M
500ºC



Diamond 2011.a.2 for SAFIR
FILE: L_6000_GL
NODES: 12943
BEAMS: 0
TRUSSES: 0
SHELLS: 12600
SOILS: 0
DISPLACEMENT PLOT (x 3)
TIME: 750.2675 sec
5.0 E-01 m
Z
X
Y



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Carlos Couto

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Thank you!

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departamento de engenharia civil